Database Processing
CS 451 / 551

Lecture 11:
Transactions and Concurrency Control

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Assignment 2 is Out!
Deadline: Nov 13, 2025 at 11:59pm

Assignment 3 will be released on Nov 13, 2025!

Transactions

- Transactions are ubiquitous!
- Examples: Banking, Online shopping, Trading, Social media, and so on.

How to define a Transaction?

How to define a Transaction?

- Transaction is a collection of operations.

- For example:
  - Moving money from one checkings account to savings account.
  - Buying a product from Amazon.

How to define a Transaction?

- Transaction is a unit of program that reads and/or writes one or more data items.

- A common way to write a transaction in popular DBMS is by placing the body of the transaction between, "**begin transaction**" and "**end transaction**".

How to define a Transaction?

- Transaction is a unit of program that reads and/or writes one or more data items.
- A common way to write a transaction in popular DBMS is by placing the body of the transaction between, “**begin transaction**” and “**end transaction**”.
- Also, the reason why transaction is termed as an indivisible unit.
  - It either executes in its entirety or nothing at all.

Definitions and Notations

- **Database:**
  - A collection of data-items or records (**A, B, C, D**, …).

- **Transactions:**
  - A set of read/write operations:
  - **R(A)** → implies Read a data-item/record A.
  - **W(A)** → implies Write a data-item/record A.

ACID Properties for a Transaction

?

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- Each database should provide the following four properties for transactions :

- **Atomicity:** Either all operations of the transaction are reflected properly in the database, or none are.

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ACID Properties for a Transaction

- Each database should provide the following four properties for transactions:

- **Atomicity:** Either all operations of the transaction are reflected properly in the database, or none are.

- **Consistency:** Execution of a transaction in isolation (that is, with no other transaction executing concurrently) preserves the consistency of the database.
  - Not referring to database consistency constraints.

- **Isolation**: For every pair of concurrent (executing at the same time) transactions Ti and Tj , either Ti finished execution before Tj started, or Ti started execution after Tj finished.
  - Transactions are unaware of other transactions executing

ACID Properties for a Transaction

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- **Isolation**: For every pair of concurrent (executing at the same time) transactions Ti and Tj , either Ti finished execution before Tj started, or Ti started execution after Tj finished.
  - Transactions are unaware of other transactions executing

- **Durability:** Once a transaction completes successfully, any changes it made to the database should persist, even if there are system failures.

ACID Properties for a Transaction

- **When do ACID properties come into play?**

ACID Properties for a Transaction

- **When do ACID properties come into play?**
  - **Concurrency!**

- In a concurrent system or database, two or more transactions may attempt to fetch the same data.

- **But, why is this an issue?**

ACID Properties for a Transaction

- **When do ACID properties come into play?**
  - **Concurrency!**

- In a concurrent system or database, two or more transactions may attempt to fetch the same data.

- **But, why is this an issue?**
  - Concurrency if not handled well can lead to ACID violations.
  - For instance. → Race conditions!

Two Concurrent Transactions

T1:

read(**A**);
A = **A** − 50;
write(**A**);
read(**B**);
B = **B** + 50;
write(**B**).

T2:

read(**A**);
temp = **A** * 0.1;
A = **A** − temp;
write(**A**);
read(**B**);
B = **B** + temp;
write(**B**)

Notice that they are accessing the same variables A and B.

Atomicity

- **What do you think happens at DBMS after you execute a transaction?**

Atomicity

- What do you think happens at DBMS after you execute a transaction?
  - The transaction **commits** after completing all the operations!
  - The transaction **aborts**.

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- **What is meant by transaction commits or aborts**?

Atomicity

- What do you think happens at DBMS after you execute a transaction?
  - The transaction **commits** after completing all the operations!
  - The transaction **aborts**.

- What is meant by a transaction commits or aborts?
  - **Commits** → The result of executing the transaction will persist.
  - **Aborts** → No trace of the transaction will exist.

Atomicity

- **DBMS guarantees atomicity.**
  - From a user's point of view: a transaction always either executes all its operations or executes none at all.

Atomicity

- **How to provide support for atomicity in the DBMS?**

Atomicity

- How to provide support for atomicity in the DBMS?

- **Two ways**:
    - Logging
    - Shadow Paging (not preferred)

Atomicity Support: Logging

Atomicity Support: Logging

- A log is like a ledger or file that records all events or actions.
- DBMS logs every action so that it can undo the actions of aborted transactions.
- Essentially, you are noting down:
  - All the operations that you executed.
  - Any record in memory/disk you added/deleted/modified.
  - And the order of performing these operations.
- All of this information is also termed as **undo records**.
- You may have heard of the black box in airplanes → A form of logging.
- Audit Trail? → A form of logging.

Atomicity Support: Shadow Paging

Atomicity Support: Shadow Paging

- **DBMS creates copies of each page**.
- Effects of a transaction are applied to a specific copy.
- Only when the transaction **commits**, the page copy is made visible to others.
- Clearly, extremely bad in performance!
- Hard to maintain and page merge may be necessary.

Consistency

- A transaction must preserve database consistency
  - If a transaction is run atomically in isolation starting from a consistent database, the database must again be consistent at the end of the transaction.

- Need to preserve the data integrity constraints like referential integrity, foreign key constraints, etc.

- Need to preserve application-dependent consistency constraints that are too complex to state using the SQL constructs for data integrity.

- **Responsibility of the programmer** who codes a transaction.

- Notice that the **C in ACID** is the only one that is not under the control of the system!

Isolation

- Users submit transactions.

- Each transaction should execute as if it is running by itself.

Isolation

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- But running one transactions at a time will give poor performance.

Isolation

- Users submit transactions.
- Each transaction should execute as if it were running by itself.
- But running one transactions at a time will give poor performance.
- With the prevalence of multi-core architecture, DBMS should take advantage of the multiple cores.
- Concurrency permits interleaving the transaction operations.
  - Interleaving transactions also permits running one transaction when another is waiting for some resource (I/O, user input, or fetching data from disk).
  - Need a mechanism to interleave transactions but make it appear as if they ran one-at-a-time.

Concurrent Transactions

- Assume that these two transactions are undergoing concurrent execution.
- **What are the possible interleaving of these two transactions**?

T1:	**T2:**
read(**A**);	read(**A**);
A = **A** − 50;	**A** = **A** * 0.95;
write(**A**);	write(**A**);
read(**B**);	read(**B**);
B = **B** + 50;	**B** = **B** * 1.05 ;
write(**B**).	write(**B**)

Concurrent Transactions

- Before we determine possible inter-leavings, we need to do a bunch of tasks.
- First, we need to know the **possible set of values for A and B** at the end of running these transactions (Say, **initially A = B = 50):**
  - **A + B = 100 * 1.05 = 105**

T1:	**T2:**
read(**A**);	read(**A**);
A = **A** − 50;	**A** = **A** * 1.05;
write(**A**);	write(**A**);
read(**B**);	read(**B**);
B = **B** + 50;	**B** = **B** * 1.05 ;
write(**B**).	write(**B**)

Concurrent Transactions

- Next, we **transform these transactions** to the database perspective.
- Specifically, we need to worry only about read/write operations as only those impact the database.

T1:	**T2:**
read(**A**);	read(**A**);
A = **A** − 50;	**A** = **A** * 0.95;
write(**A**);	write(**A**);
read(**B**);	read(**B**);
B = **B** + 50;	**B** = **B** * 1.05 ;
write(**B**).	write(**B**)

Concurrent Transactions

- We need to worry only about read/write operations as only those impact the database.

- So, we **re-write these transactions** as just a set of read/write operations.

T1:	T2:
Begin	**Begin**
read(**A**)	read(**A**)
write(**A**)	write(**A**)
read(**B**)	read(**B**)
write(**B**)	write(**B**)
End	**End**

Serial Execution

- One legal interleaving is **serial execution**:

- Either T1 → T2, or T2 → T1.
    - Here, the notation T1 → T2 states that first execute transaction T1, and then execute T2.

Serial Execution

Time

T1:	T2:
Begin	
read(**A**)	
write(**A**)	
read(**B**)	
write(**B**)	
End	
	Begin
	read(**A**)
	write(**A**)
	read(**B**)
	write(**B**)
	End

Time

T1:	T2:
	Begin
	read(**A**)
	write(**A**)
	read(**B**)
	write(**B**)
	End
Begin	
read(**A**)	
write(**A**)	
read(**B**)	
write(**B**)	
End	

Serial Execution

- **Serial execution** is a legal interleaving:

- It guarantees **isolation**.

- But, serial execution does not take advantage of multi-core architecture.

Schedule

- A **schedule** states the **order of executing** different operations of a transaction.

- The following is a **serial schedule** as it **does not interleave** the operations of different transactions.

Time	T1:	T2:
	Begin	
	read(**A**)	
	write(**A**)	
	read(**B**)	
	write(**B**)	
	End	
		Begin
		read(**A**)
		write(**A**)
		read(**B**)
		write(**B**)
		End

Another Interleaving (I)

Time

T1:	T2:
Begin	
read(**A**)	
write(**A**)	
	Begin
	read(**A**)
	write(**A**)
read(**B**)	
write(**B**)	
End	
	read(**B**)
	write(**B**)
	End

Is this a legal interleaving?

Another Interleaving (I)

Time

T1:	T2:
Begin	
read(**A**)	
write(**A**)	
	Begin
	read(**A**)
	write(**A**)
read(**B**)	
write(**B**)	
End	
	read(**B**)
	write(**B**)
	End

Is this a legal interleaving?

Yes!

Another Interleaving (II)

	T1:	T2:
Time	**Begin**	
	read(**A**)	
		Begin
		read(**A**)
		write(**A**)
	write(**A**)	
	read(**B**)	
	write(**B**)	
	End	read(**B**)
		write(**B**)
		End

Is this a legal interleaving?

Another Interleaving (II)

Time

T1:	T2:
Begin	
read(**A**)	
	Begin
	read(**A**)
	write(**A**)
write(**A**)	
read(**B**)	
write(**B**)	
End	read(**B**)
	write(**B**)
	End

Is this a legal interleaving?

No!

T1's **write(A)** does not follow its **read(A)**.

Conflicting Transactions

Two transactions T1 and T2 if they **concurrently access the same variable** and at least one of that access is a **write** operation, then they **conflict**!

Conflicting Transactions

- Interleaving concurrent transactions can lead to the following three anomalies:
  - Read-Write Conflicts (**R-W**)
  - Write-Read Conflicts (**W-R**)
  - Write-Write Conflicts (**W-W**)

Read-Write Conflict

- **Unrepeatable Read?**

Read-Write Conflict

- **Unrepeatable Read**: A transaction gets different values when reading the same object multiple times.

- Say, initially A = 50.

T1:	**T2:**
Begin	
read(**A**)	
	Begin
	read(**A**)
	write(**A**)
read(**A**)	**End**
End	

Read-Write Conflict

- **Unrepeatable Read**: A transaction gets different values when reading the same object multiple times.

- Say, initially A = 50.

	T1:	T2:
	Begin	
Output → 50	read(**A**)	
		Begin
		read(**A**)
		write(**A**)
	read(**A**)	**End**
	End	

Read-Write Conflict

- **Unrepeatable Read**: A transaction gets different values when reading the same object multiple times.

- Say, initially A = 50.

Output → 50

T1:	T2:
Begin	
read(**A**)	
	Begin
	read(**A**)
	write(**A**)
read(**A**)	**End**
End	

Read-Write Conflict

- **Unrepeatable Read**: A transaction gets different values when reading the same object multiple times.

- Say, initially A = 50.

	T1:	T2:
	Begin	
A = 100	read(**A**)	
		Begin
		read(**A**)
		write(**A**)
	read(**A**)	**End**
	End	

Read-Write Conflict

- **Unrepeatable Read**: A transaction gets different values when reading the same object multiple times.

- Say, initially A = 50.

	T1:	T2:
	Begin	
Output → 100	read(**A**)	
		Begin
		read(**A**)
		write(**A**)
	read(**A**)	**End**
	End	

Write-Read Conflict

- **Dirty Read?**

Write-Read Conflict

- **Dirty Read**: One transaction reads data written by another transaction that has not committed yet.

- Say, initially A = 50.

T1:	**T2:**
Begin	
read(**A**)	
write(**A**)	**Begin**
	read(**A**)
	write(**A**)
	End
Abort	

Write-Read Conflict

- **Dirty Read**: One transaction reads data written by another transaction that has not committed yet.

- Say, initially A = 50.

	T1:	T2:
	Begin	
Output → 50	read(**A**)	
	write(**A**)	**Begin**
		read(**A**)
		write(**A**)
		End
	Abort	

Write-Read Conflict

- **Dirty Read**: One transaction reads data written by another transaction that has not committed yet.

- Say, initially A = 50.

A = 100

T1:	T2:
Begin	
read(**A**)	
write(**A**)	**Begin**
	read(**A**)
	write(**A**)
	End
Abort	

Write-Read Conflict

- **Dirty Read**: One transaction reads data written by another transaction that has not committed yet.

- Say, initially A = 50.

Output → 100

T1:	T2:
Begin	
read(**A**)	
write(**A**)	**Begin**
	read(**A**)
	write(**A**)
	End
Abort	

Write-Read Conflict

- **Dirty Read**: One transaction reads data written by another transaction that has not committed yet.

- Say, initially A = 50.

Output → 150

T1:	T2:
Begin	
read(**A**)	
write(**A**)	**Begin**
	read(**A**)
	write(**A**)
	End
Abort	

Write-Read Conflict

- **Dirty Read**: One transaction reads data written by another transaction that has not committed yet.
- Say, initially A = 50.

Transaction T1 has to be aborted

T1:	**T2:**
Begin	
read(**A**)	
write(**A**)	**Begin**
	read(**A**)
	write(**A**)
	End
Abort	

Write-Write Conflict

- **Lost Update?**

Write-Write Conflict

- **Lost Update** → One transaction overwrites uncommitted data from another uncommitted transaction.

- Say, initially A = 50.

T1:	**T2:**
Begin	
read(**A**)	
	Begin
	read(**A**)
write(**A**)	
	write(**A**)
	write(**B**)
	End
write(**B**)	
End	

Write-Write Conflict

- **Lost Update →** One transaction overwrites uncommitted data from another uncommitted transaction.

- Say, initially A = 50.

	T1:	**T2:**
	Begin	
	read(**A**)	
Output → 50		**Begin**
		read(**A**)
	write(**A**)	
		write(**A**)
		write(**B**)
		End
	write(**B**)	
	End	

Write-Write Conflict

- **Lost Update →** One transaction overwrites uncommitted data from another uncommitted transaction.

- Say, initially A = 50.

T1:	T2:
Begin	
read(**A**)	
	Begin
	read(**A**)
write(**A**)	
	write(**A**)
	write(**B**)
	End
write(**B**)	
End	

Output → 50

Write-Write Conflict

- **Lost Update** → One transaction overwrites uncommitted data from another uncommitted transaction.

- Say, initially A = 50.

A = 100

T1:	**T2:**
Begin	
read(**A**)	
	Begin
	read(**A**)
write(**A**)	
	write(**A**)
	write(**B**)
	End
write(**B**)	
End	

Write-Write Conflict

- **Lost Update →** One transaction overwrites uncommitted data from another uncommitted transaction.

- Say, initially A = 50.

	T1:	T2:
	Begin	
	read(**A**)	
		Begin
A = 100		read(**A**)
	write(**A**)	
Previous update missed!		write(**A**)
		write(**B**)
		End
	write(**B**)	
	End	

Write-Write Conflict

- **Lost Update →** One transaction overwrites uncommitted data from another uncommitted transaction.

- Say, initially A = 50.

	T1:	**T2:**
	Begin	
	read(**A**)	
A = 100		**Begin**
		read(**A**)
	write(**A**)	
B = 100		write(**A**)
		write(**B**)
		End
	write(**B**)	
	End	

Write-Write Conflict

- **Lost Update →** One transaction overwrites uncommitted data from another uncommitted transaction.

- Say, initially A = 50.

	T1:	T2:
	Begin	
	read(**A**)	
A = 100		**Begin**
		read(**A**)
	write(**A**)	
B = 150		write(**A**)
		write(**B**)
		End
	write(**B**)	
	End	

Write-Write Conflict

- **Lost Update →** One transaction overwrites uncommitted data from another uncommitted transaction.

- Say, initially A = 50.

	T1:	T2:	
	Begin		
	read(**A**)		
A = 100		**Begin**	This leads to unexpected results of 100,150 when it should have been 150, 150.
		read(**A**)	
	write(**A**)		
B = 150		write(**A**)	
		write(**B**)	
		End	
	write(**B**)		
	End		

Isolation Support: Concurrency Control

- A **concurrency control protocol** lays down the mechanism for the DBMS to decide a legal/valid schedule of transactions.

- What are the **types** of concurrency control protocols?

Isolation Support: Concurrency Control

- A concurrency control protocol lays down the mechanism for the DBMS to decide legal/valid schedule of transactions.

- What are the types of concurrency control protocols?

- **Pessimistic:** Prevent problems from arising in the first place.

Isolation Support: Concurrency Control

- A concurrency control protocol lays down the mechanism for the DBMS to decide legal/valid schedule of transactions.

- What are the types of concurrency control protocols?

- **Pessimistic:** Prevent problems from arising in the first place.

- **Optimistic:** Assume that conflicts are rare; deal with them after they occur.

Isolation Support: Concurrency Control

- A concurrency control protocol lays down the mechanism for the DBMS to decide legal/valid schedule of transactions.
- What are the types of concurrency control protocols?
- **Pessimistic:** Prevent problems from arising in the first place.
- **Optimistic:** Assume that conflicts are rare; deal with them after they occur.
- **But, how does a concurrency control protocol determine a valid schedule?**

Serializable Schedules

- **Serial Schedule** → A schedule that does not interleave the operations of different transactions.

- **Equivalent Schedule** → For any database state, the effect of executing the first schedule is identical to the effect of executing the second schedule.

- **Serializable Schedule?**

Serializable Schedules

- **Serial Schedule** → A schedule that does not interleave the operations of different transactions.

- **Equivalent Schedule** → For any database state, the effect of executing the first schedule is identical to the effect of executing the second schedule.

- **Serializable Schedule** → A schedule that is equivalent to some serial execution of the transactions (serial schedule).

Serializable Schedules

- **Serial Schedule →** A schedule that does not interleave the operations of different transactions.

- **Equivalent Schedule →** For any database state, the effect of executing the first schedule is identical to the effect of executing the second schedule.

- **Serializable Schedule →** A schedule that is equivalent to some serial execution of the transactions (serial schedule).

- If each transaction preserves consistency, then the corresponding serializable schedule preserves consistency!

Isolation Levels vs. Consistency Levels

Isolation Levels	Consistency Levels

Isolation Levels vs. Consistency Levels

Isolation Levels	Consistency Levels
• **Correspond** to the **I in ACID**. • **Database isolation** is the ability of a database to allow a transaction to execute as if there are no other concurrently running transactions. • Greater the guaranteed isolation among the transactions, lesser the system performance. • **Isolation levels** trade off isolation guarantees for improved performance.	

Isolation Levels vs. Consistency Levels

Isolation Levels	Consistency Levels
• **Correspond** to the **I in ACID**.	• **Do not correspond to C in ACID**.
• **Database isolation** is the ability of a database to allow a transaction to execute as if there are no other concurrently running transactions.	• Unlike the C in ACID, the **database consistency** refers to the rules that make a **concurrent**, **distributed system** appear as a **single-threaded, centralized system**.
• Greater the guaranteed isolation among the transactions, lesser the system performance.	• **Reads** at a particular point in time **must reflect the most recently completed write** (in real-time) of that data item, no matter which server processed that write.
• **Isolation levels** trade off isolation guarantees for improved performance.	• **Consistency levels** trade off read results for improved performance.

Isolation Levels vs. Consistency Levels

- More simply said:
  - Whenever you talk about transaction isolation, you will be talking about isolation levels.
  - Whenever you talk about individual operations like read/write, you will talk about consistency levels.

Serializable Isolation Level

- Also known as serializability.

- The ability of a DBMS to run transactions in parallel, but in a way that they are running, **serially**, that is, **one after another**.

- Thus, if the DBMS can ensure a serializable schedule for a set of transactions, then we say that the DBMS is offering serializability or serializable isolation level.

Levels of Serializability

- **Conflict Serializability**
  - Most DBMS try to support this.

- **View Serializability**
  - No DBMS can do this!

Dependency Graphs

- **Help to determine the level of serializability among other things.**
- **How can you create a dependency graph?**

Dependency Graphs

- Help to determine the level of serializability among other things.
- How can you create a dependency graph?
- One node per transaction.
- **Add an edge from transaction Ti to transaction Tj** if you the following are met:
  - An operation **Oi of Ti** conflicts with an operation **Oj of Tj**.
  - **Oi** appears earlier in the schedule than **Oj**.
- Also known as **precedence graph**.

Dependency Graphs Example I

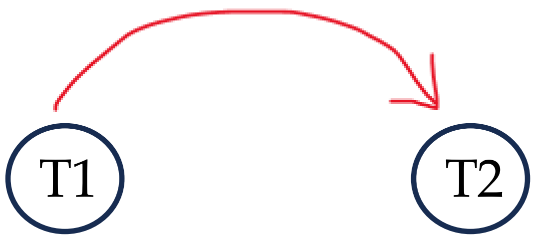
Time

T1:	**T2:**
Begin	
read(**A**)	
write(**A**)	
	Begin
	read(**A**)
	write(**A**)
read(**B**)	
write(**B**)	
End	
	read(**B**)
	write(**B**)
	End

Dependency Graphs Example I

Time

T1:	T2:
Begin	
read(**A**)	
write(**A**)	
	Begin
	read(**A**)
	write(**A**)
read(**B**)	
write(**B**)	
End	
	read(**B**)
	write(**B**)
	End



T2 depends on T1

W-R and W-W Conflicts

Dependency Graphs Example II

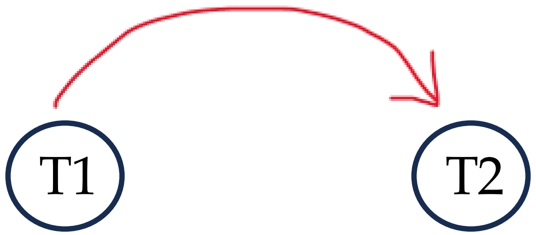
Time

T1:	**T2:**
Begin	
read(**A**)	
write(**A**)	
	Begin
	read(**A**)
	write(**A**)
	read(**B**)
	write(**B**)
	End
read(**B**)	
write(**B**)	
End	

Dependency Graphs Example II

Time

T1:	**T2:**
Begin	
read(**A**)	
write(**A**)	
	Begin
	read(**A**)
	write(**A**)
	read(**B**)
	write(**B**)
	End
read(**B**)	
write(**B**)	
End	

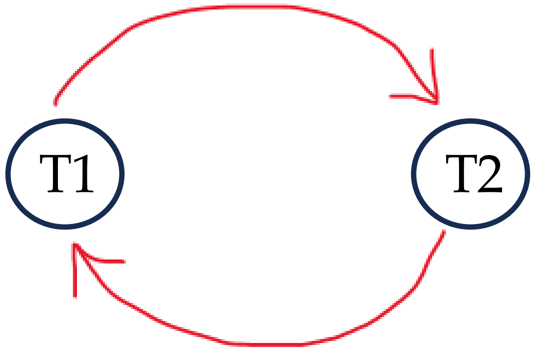


W-R and W-W Conflicts

Dependency Graphs Example II

Time

T1:	T2:
Begin	
read(**A**)	
write(**A**)	
	Begin
	read(**A**)
	write(**A**)
	read(**B**)
	write(**B**)
	End
read(**B**)	
write(**B**)	
End	



Conflict Cycle!

W-R and W-W Conflicts

Conflict Serializability

Conflict Serializability

- Two schedules are **conflict equivalent** if and only if:
  - They involve the **same actions** of the same transactions.
  - Every pair of conflicting actions is ordered the same way.

- A schedule S is **conflict serializable** if S is conflict equivalent to some serial schedule.

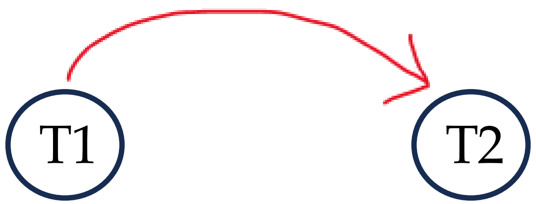
- You can **transform** a conflict serializable schedule S into a serial schedule by swapping consecutive non-conflicting operations of different transactions.

- A schedule is conflict serializable iff its **dependency graph is acyclic**.

Conflict Serializability: Example I

Time

T1:	T2:
Begin	
read(**A**)	
write(**A**)	
	Begin
	read(**A**)
	write(**A**)
read(**B**)	
write(**B**)	
End	
	read(**B**)
	write(**B**)
	End



Is this conflict serializable?

Conflict Serializability: Example I

Time

T1:	**T2:**
Begin	
read(**A**)	
write(**A**)	
	Begin
	read(**A**)
	write(**A**)
read(**B**)	
write(**B**)	
End	
	read(**B**)
	write(**B**)
	End

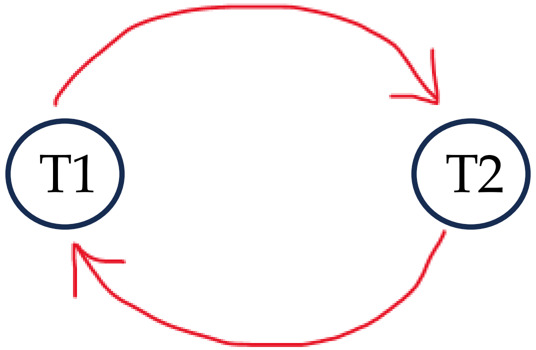
Is this conflict serializable?

Yes!

Conflict Serializability: Example II

T1:	T2:
Begin	
read(**A**)	
write(**A**)	
	Begin
	read(**A**)
	write(**A**)
	read(**B**)
	write(**B**)
	End
read(**B**)	
write(**B**)	
End	

Time

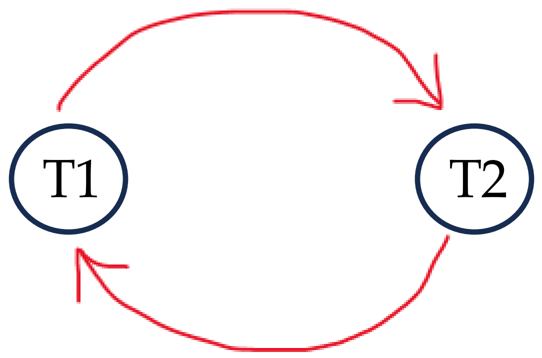


Is this conflict serializable?

Conflict Serializability: Example II

Time

T1:	T2:
Begin	
read(**A**)	
write(**A**)	
	Begin
	read(**A**)
	write(**A**)
	read(**B**)
	write(**B**)
	End
read(**B**)	
write(**B**)	
End	



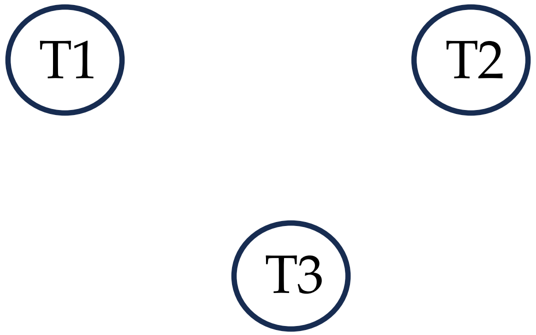
Is this conflict serializable?

No!

Conflict Serializability: Example III

Time

T1:	T2:	T3:
Begin		
read(**A**)		
write(**A**)		
		Begin
		read(**A**)
		write(**A**)
	Begin	**End**
	read(**B**)	
	write(**B**)	
	End	
read(**B**)		
write(**B**)		
End		

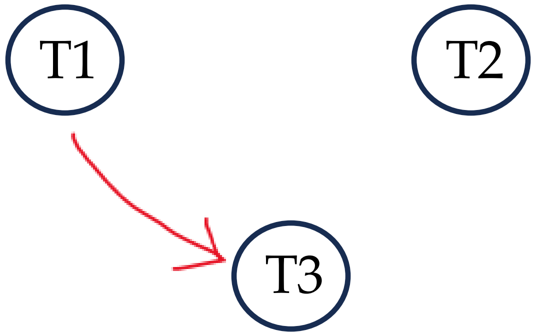


Is this conflict serializable?

Conflict Serializability: Example III

Time

T1:	**T2:**	**T3:**
Begin		
read(**A**)		
write(**A**)		
		Begin
		read(**A**)
		write(**A**)
		End
	Begin	
	read(**B**)	
	write(**B**)	
	End	
read(**B**)		
write(**B**)		
End		

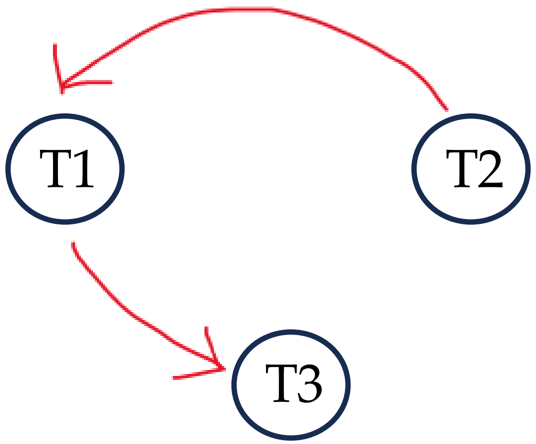


Is this conflict serializable?

Conflict Serializability: Example III

Time

T1:	T2:	T3:
Begin		
read(**A**)		
write(**A**)		
		Begin
		read(**A**)
		write(**A**)
		End
	Begin	
	read(**B**)	
	write(**B**)	
	End	
read(**B**)		
write(**B**)		
End		

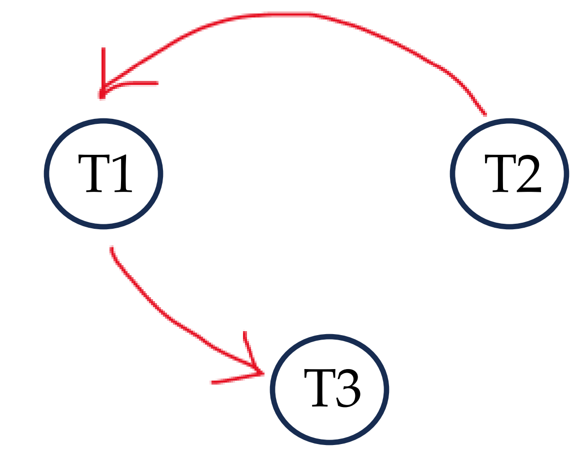


Is this conflict serializable?

Conflict Serializability: Example III

Time

T1:	T2:	T3:
Begin		
read(**A**)		
write(**A**)		
		Begin
		read(**A**)
		write(**A**)
		End
	Begin	
	read(**B**)	
	write(**B**)	
	End	
read(**B**)		
write(**B**)		
End		



Is this conflict serializable?

Is this equivalent to a serial schedule?

Yes! {T2, T1, T3}
T2 should run before T3!

Conflict Serializability: Example IV

Time

T1:	T2:
Begin	
read(**A**)	
write(**A**)	**Begin**
	read(**A**)
	read(**B**)
	End
read(**B**)	
write(**B**)	
End	

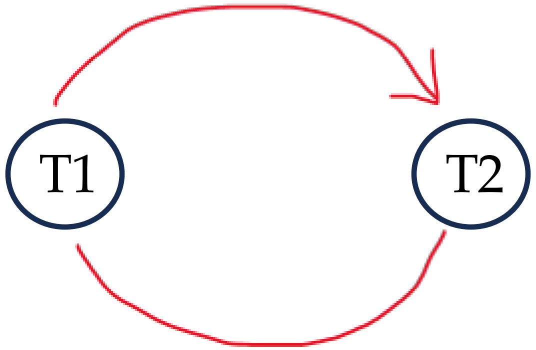
T1 T2

Is this conflict serializable?

Conflict Serializability: Example IV

Time

T1:	**T2:**
Begin	
read(**A**)	
write(**A**)	**Begin**
	read(**A**)
	read(**B**)
	End
read(**B**)	
write(**B**)	
End	



Is this conflict serializable?

No!

Determining Serializability Order from Dependence Graph

Determining Serializability Order from Dependence Graph

- Dependence graph only dictates the dependency between the transactions.

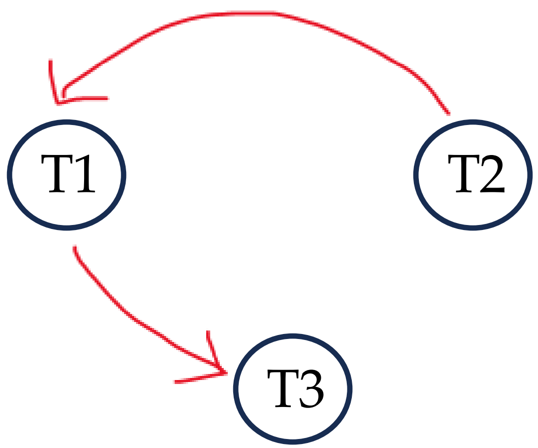
- To find the serializability order of these transactions, you run **topological sort**.

- Can there be multiple possible serializability orders?

Determining Serializability Order from Dependence Graph

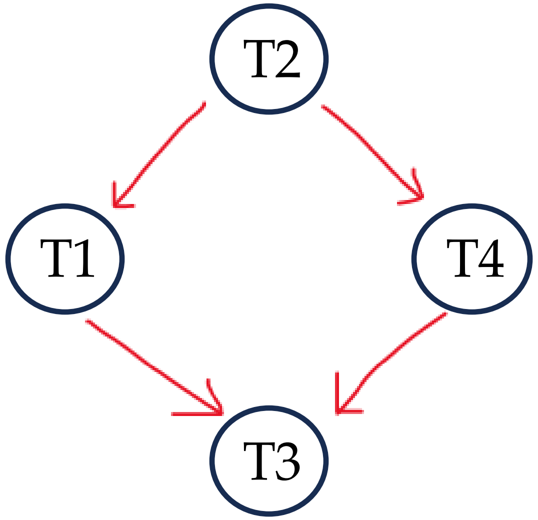
- Dependence graph only dictates the dependency between the transactions.
- To find the serializability order of these transactions, you run **topological sort**.
- Can there be multiple possible serializability orders?
  - **Yes!**
  - Not every pair of transactions are dependent on each other.

Determining Serializability Order from Dependence Graph



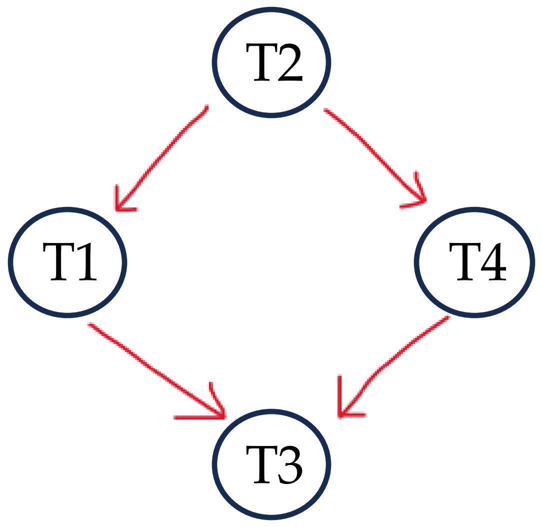
Serializability order: {T2, T1, T3}

Determining Serializability Order from Dependence Graph



Serializability order?

Determining Serializability Order from Dependence Graph



Serializability orders: {T3, T1, T4, T2} or
{T3, T4, T1, T2}

View Serializability

View Serializability

- **View Serializability** essentially states that if the output of a schedule matches the expectation, then the schedule is view serializable even if it is not conflict serializable.

- **Formal Definition**: Schedules **S1** and **S2** are **view equivalent** if
  - T1 reads initial value of A in S1, then T1 also reads initial value of A in S2.
  - T1 reads value of A written by T2 in S1, then T1 also reads value of A written by T2 in S2 .
  - T1 writes final value of A in S1, then T1 also writes final value of A in S2 .

View Serializability

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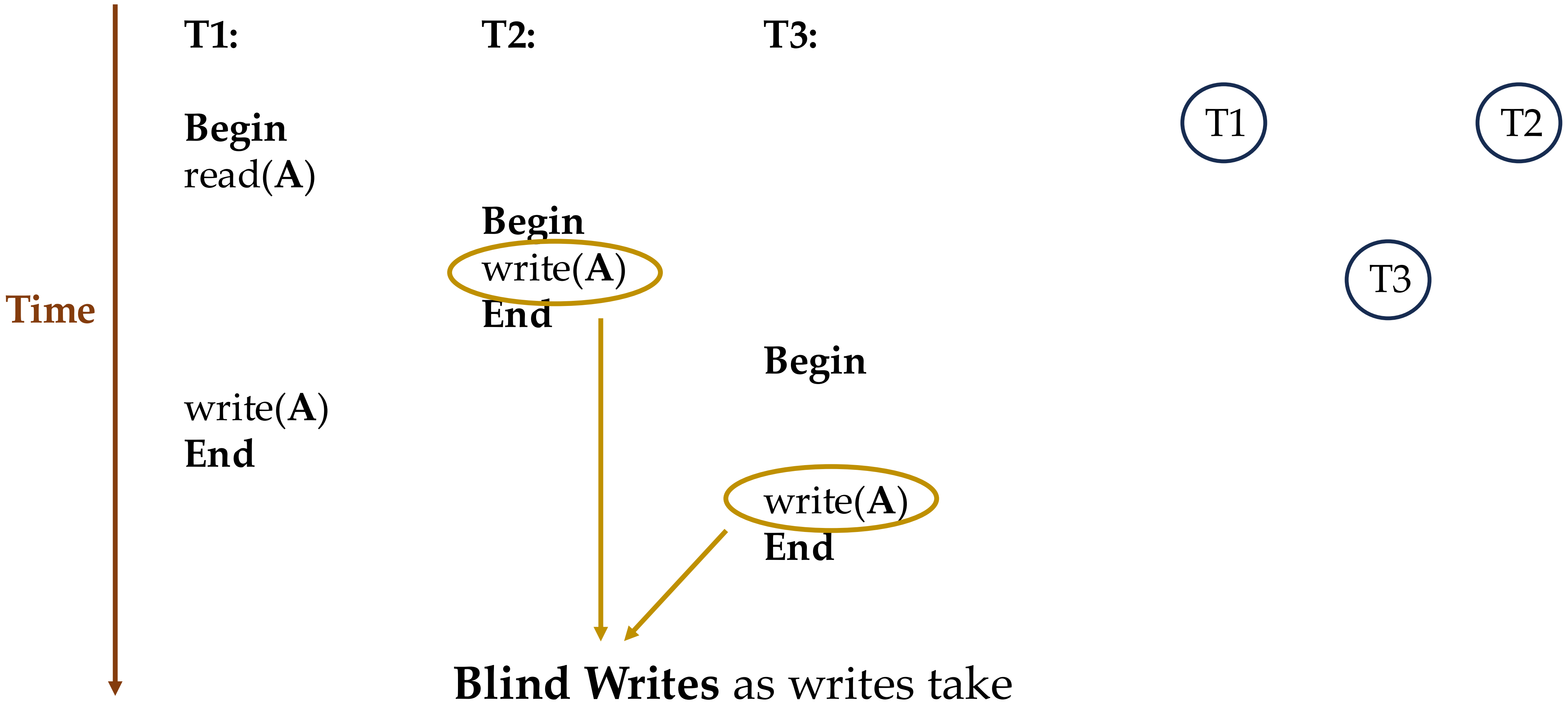
- **Formal Definition**: Schedules **S1** and **S2** are **view equivalent** if
  - T1 reads initial value of A in S1, then T1 also reads initial value of A in S2.
  - T1 reads value of A written by T2 in S1, then T1 also reads value of A written by T2 in S2 .
  - T1 writes final value of A in S1, then T1 also writes final value of A in S2 .

- View Serializability supports more schedules than Conflict Serializability.

View Serializability

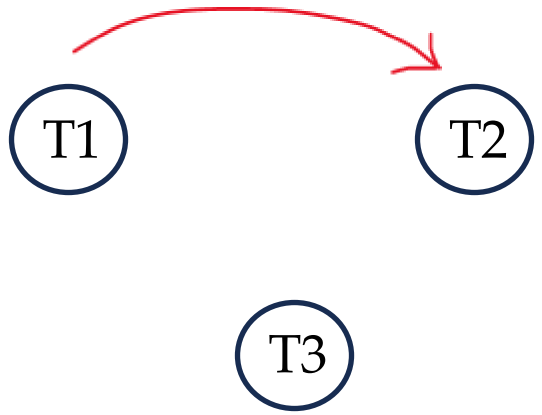


Blind Writes as writes take place without reading.

View Serializability

Time

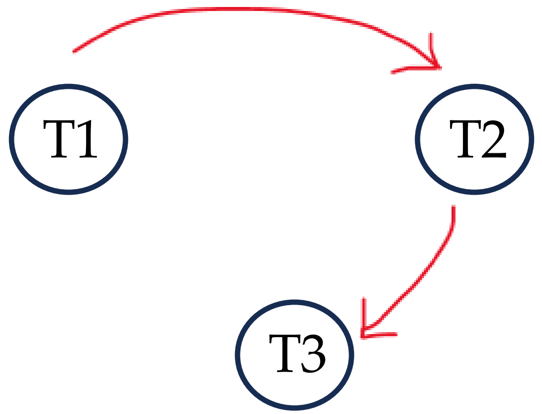
T1:	T2:	T3:
Begin		
read(**A**)		
	Begin	
	write(**A**)	
	End	
		Begin
write(**A**)		
End		
		write(**A**)
		End



View Serializability

Time

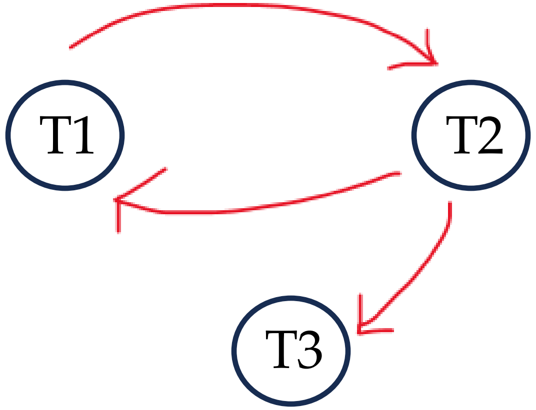
T1:	T2:	T3:
Begin		
read(**A**)		
	Begin	
	write(**A**)	
	End	
		Begin
write(**A**)		
End		
		write(**A**)
		End



View Serializability

Time

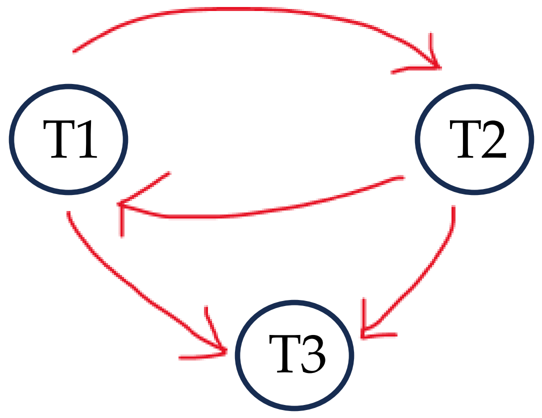
T1:	T2:	T3:
Begin		
read(**A**)		
	Begin	
	write(**A**)	
	End	
		Begin
write(**A**)		
End		
		write(**A**)
		End



View Serializability

Time

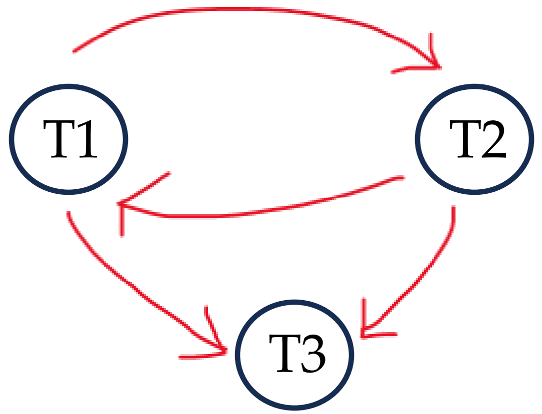
T1:	T2:	T3:
Begin		
read(**A**)		
	Begin	
	write(**A**)	
	End	
		Begin
write(**A**)		
End		
		write(**A**)
		End



View Serializability

Time

T1:	T2:	T3:
Begin		
read(**A**)		
	Begin	
	write(**A**)	
	End	
		Begin
write(**A**)		
End		
		write(**A**)
		End



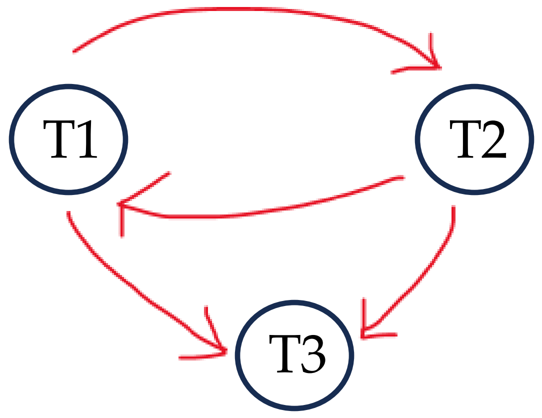
Is this conflict serializable?

No!

View Serializability

Time

T1:	T2:	T3:
Begin		
read(**A**)		
	Begin	
	write(**A**)	
	End	
		Begin
write(**A**)		
End		
		write(**A**)
		End



Is this view serializable?

View Serializability

Time

T1:	T2:	T3:
Begin		
read(**A**)		
	Begin	
	write(**A**)	
	End	
		Begin
write(**A**)		
End		
		write(**A**)
		End

View Equivalent Schedules

T1:	T2:	T3:
Begin		
read(**A**)		
write(**A**)		
End		
	Begin	
	write(**A**)	
	End	
		Begin
		write(**A**)
		End

Is this view serializable? Yes!